

## Chapter 20

# Forest Ecosystem Services As Production Inputs

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Are we cutting down tropical forests too rapidly and too extensively? If so, why? Answers to both questions are obscured in some ways by insufficient and unreliable data on the economic worth of forest ecosystem services. It is clear, however, that rapid, excessive cutting of forests can irreversibly and substantively impair ecosystem functions, thereby endangering the flow of several socially valuable goods and services from standing forests. One reason for such excessive deforestation is failure to consider the full range of goods and services provided by the forests, particularly latent and complex ecosystem services.

Forests provide ecosystem services by sequestering carbon, maintaining habitat and biodiversity, stabilizing hydrological flows, mitigating soil erosion, and improving microclimates. Public protection of tropical forests is necessary because the market mechanism cannot provide the optimal level of ecosystem services. The level of public support for forest protection depends on the net benefits of providing these services. Recent surveys of valuation studies reveal that economic benefits of forest ecosystem services are not well understood and are rarely quantified (WRI 2000). Two challenges are posed in the literature. First, recent reviews show that (1) ecosystem valuation studies have framed the valuation question incorrectly and have applied inappropriate methods (Bockstael et al. 2000), and (2) valuation studies have overlooked livelihood values of natural resources in developing countries, focusing largely on amenity values in developed countries (Deacon et al. 1998). Second, valuation of ecological services that are inputs into production processes have typically relied on data-intensive approaches, such as the measurement of full profit functions, instead of focusing on

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demand for a weak complement, which substantially reduces the data requirements (Huang and Smith 1998). This chapter addresses these issues with a case study from Indonesia in which forest protection policies in upstream watersheds stabilize hydrological flows in downstream farms.

## **1. DEFINING AND VALUING FOREST ECOSYSTEM SERVICES**

### **1.1 What Are Forest Ecosystem Services?**

Adapting a definition by Daily (1997), forest ecosystem services are the conditions and processes through which forest ecosystems, and the species that make them up, sustain and fulfill human life. Forests maintain biodiversity and the production of ecosystem goods, such as timber and pharmaceutical precursors, and ecosystem services that are actual life-support functions, such as microclimate regulation and watershed services. Forest ecosystems also confer many intangible aesthetic and cultural benefits. Below we catalog a longer list of goods and services from forest ecosystems. Our list of potential goods and services focuses on direct and indirect benefits to human beings because valuation, as described here, is mostly for people (Freeman 1996).

The World Resources Institute (WRI 2000) categorizes forest ecosystem services into two basic groups. Goods include timber, fuelwood, drinking and irrigation water, fodder, nontimber forest products (such as vines, bamboo, and leaves, as described in chapter 15), food (honey, mushrooms, and fruits), and genetic resources. Services include removing air pollution, emitting oxygen, cycling nutrients, maintaining an array of watershed functions, maintaining biodiversity, sequestering carbon (further discussed in chapter 13), moderating weather extremes, generating soil, providing employment, providing human and wildlife habitat, contributing aesthetic beauty, and providing recreation (further discussed in chapter 19).<sup>1</sup>

### **1.2 Taking Stock of Forest Ecosystems Services**

WRI (2000) provides an excellent evaluation of the current state of forest ecosystems, discussing timber, fuelwood, watershed services, biodiversity and carbon, noting that forest cover, now accounting for about 25% of the world's land surface, has been reduced by 20% to 50% since preagricultural times. Most developing countries rely on timber exports, while in most industrialized countries, the majority of timber comes from production forests. Fuelwood accounts for about 15% to 80% of the primary energy

supply in developing countries, with use concentrated among the poor. Forests harbor about 66% of the known terrestrial species and have the highest species diversity, including threatened species, and endemism of any ecosystem. Forest vegetation and soils sequester nearly 40% of all terrestrial stored carbon.

Nearly 30% of the world's major watersheds—particularly in tropical montane forest regions—have lost more than 75% of their original forest cover. The greatest threats to forest extent and condition today are conversion to other land uses and fragmentation by agriculture, logging, and roads. Although 66% of all fuelwood comes from roadsides, community woodlots, and wood industry residues, fuelwood collection causes local deforestation in parts of Asia, Africa, and Latin America (WRI, 2000).

### 1.3 Valuing Ecosystem Services

Arrow et al. (2000) call for ecosystem valuation because ecosystem management requires detailed bookkeeping of costs and benefits and evaluation of tradeoffs. We approach this issue by addressing three broad questions: Why value? What can be valued? How to value?

Valuation, described as the search for an integrative metric, is conducted for one of three reasons (Pritchard et al. 2000): (1) to show that natural systems are indisputably linked to human welfare and are represented in the decision-making process, (2) to describe the relative importance of various ecosystem types, or (3) to justify or critique particular decisions in particular places, e.g., cost/benefit analyses. Consequently, valuation appeals to diverse constituencies ranging from free-market advocates who believe it will improve economic efficiency, to managers in search of integrative metrics to guide decision making, to environmentalists who believe that the standing of neglected natural resources will be enhanced by the recognition of their value (Carpenter and Turner 2000). In general, while economic valuation of ecosystem services is neither necessary nor sufficient for conservation (Heal 2000), it can guide public decisions and ecosystem management by providing estimates of the incremental value or cost of changes in ecosystem conditions (Bockstael et al. 2000).

Economic valuation of forest ecosystem services can only address services that are directly or indirectly useful to human beings, including nonconsumptive uses that provide some psychological benefit. A serious discussion of what can be valued was triggered by attempts to value all of nature's services (e.g., Costanza et al. 1997). While consensus has not been reached, a critical review of such global valuation studies (Bockstael et al. 2000) provides three vital considerations for ecosystem valuation. First, analysts should study possible changes to specific forest ecosystem

conditions. All-or-nothing changes are irrelevant for policy analysis and uninteresting, perhaps even trivial, from an academic perspective. Second, we should not scale up small changes in specific and localized components of individual forest ecosystems to generate aggregate forest ecosystem values because ecosystem valuation fails simple additivity tests.<sup>2</sup> Finally, the analysis must satisfy the most fundamental economic valuation criterion, namely, that ecosystem values do not exceed ability to pay.

Ecosystem valuation is complicated by the fact that ecosystem services, as quasi-public goods and externalities, are not well accounted for in market mechanisms (Arrow et al. 2000). The key to valuing a change in an ecosystem function lies in establishing the link between that function and some service flow valued by people. The analysis must reflect the intricate web of physical relationships between processes and conditions that link causes and effects in different parts of the ecosystem. If that link can be established, then the economist's concept of derived demand can be applied (Freeman 1996). Some ecosystem functions are related to useful ecosystem services, such as photosynthesis producing useful plant material. Other examples are indirect, subtle, and latent, such as photosynthesis generating wildflowers that support bees, which pollinate commercial fruits. Once we establish how a policy will change photosynthesis capacity and therefore plant and fruit production, we can analyze the demand for the plant material or the commercial fruits to derive a measure of willingness to pay for (or willingness to accept) changes in policy-induced photosynthetic services. These money measures are based on consumer sovereignty as opposed to some external prescription of how consumers should make choices (Bockstael et al. 2000). Travel cost (chapter 19), contingent valuation (chapter 17), hedonic property and wage, and productivity analysis are among the typical valuation methods that apply derived demand theory (see Freeman 1993).

### **1.3.1 What Forest Ecosystem Services Have Been Valued?**

The study by Costanza et al. (1997), which included some forest ecosystem services, failed to satisfy the basic tenets of valuation. Other attempts to link forest ecosystem functions to economically valuable ecosystem services are rare (Freeman 1996). Researchers have measured values for specific attributes of forests (particularly for recreation uses), though the analysis has typically not included ecological models that link the attributes to specific forest ecosystem functions. We observe similar gaps in studies of two other ecosystems, wetlands and atmosphere, which are more often the subject of economic analysis. In both cases, some proxy for the ecosystem service (e.g., saline concentrations in estuarine wetlands or

atmospheric ozone concentrations in farming counties) is related to a production activity (e.g., shrimp or corn), but the link between the ecosystem functioning and the service has not been spelled out.

Economic analyses of watershed services have typically concentrated on soil erosion effects (Pattanayak [forthcoming]). Empirical economic analyses of soil erosion have used resource accounting approaches, econometric production functions methods, or mathematical programming models. In the econometric approach, the production functions are usually either aggregative (nation or statewide), thereby losing site-specific details, or simple, with just two or three arguments.<sup>3</sup> In all cases the value of soil erosion is estimated in terms of its effect on economic productivity. By proposing the use of econometric methods to analyze ecosystem services as production inputs, the approach employed in this chapter most resembles soil valuation studies that use production functions. The critical distinction between these studies and our proposal relates to the link between ecosystem functions and the resulting services. The erosion studies typically focus on managed agronomic systems and on-farm economic productivity losses. They do not discuss or rigorously analyze off-site consequences of or the linkages with upstream ecological phenomena.

### **1.3.2 Analytical Framework**

The economic principles for valuation are straightforward, and the economic value of ecosystem services can be viewed as the outcome of three sets of functional relationships (Freeman 1993; subsequently adapted for ecosystem services by Kramer et al. 1997 and Pattanayak [forthcoming]). Public policies combined with private decisions affect forested watersheds, change watershed flows, and, thereby, generate changes in ecosystem services. These services affect private production activities of economic agents and consequently their economic welfare. The change in welfare, evaluated in terms of market prices of private commodities, is the use value of ecosystem services.

## **1.4 Freeman's Three-Stage Approach**

The first stage of analysis relates an index of ecosystem service (e.g., quantity or rates of runoff, streamflow, erosion, and sediment) to public and private land use decisions (e.g., national parks or on-farm agroforestry) that are amenable to public policy (figure 20.1). The structural relationship is conditioned by time lags and various environmental characteristics, including geologic substrate, topography, and climate. Direct and indirect public policies thus cause changes in ecosystem services. Variations between

policies and their impact, within the available data set, enable the analyst to use the associated variations in ecosystem services to compute economic values. Exclusive private provision, without any public support (such as subsidies, taxes, provision of information, and technical expertise and credit) is not typical because of the inherent ‘public good’ characteristics of the provision process and of the ecosystem services themselves.

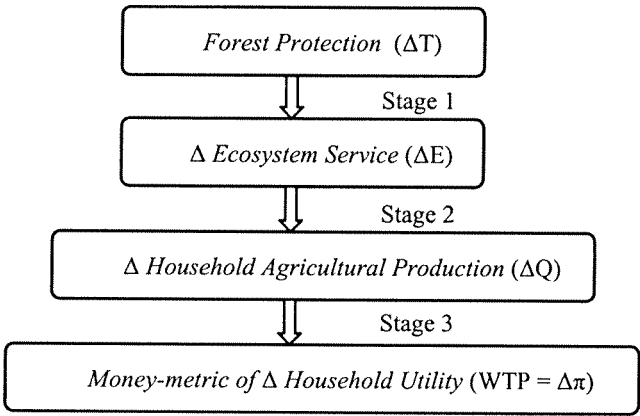


Figure 20.1. Freeman three-stage framework for valuation

The second stage quantifies human use of the ecosystem service. Households use their labor and other inputs, conditional on the nonmarket ecosystem service and other fixed inputs, to produce a vector of commodities for the market and domestic consumption. Ecosystem services can thus be considered a fixed input in either home production of final services, which yield utility (household production theory), or agricultural production (production theory).<sup>4</sup>

In the third stage, the economic value of an ecosystem service or willingness to pay (WTP) for an ecosystem service is determined in terms of the market value of commodities related to that ecosystem service. Models from welfare economics are used to express the money-metric of utility changes or WTP in terms of expenditures changes that depend on the utility level and therefore consumption choices (Freeman 1993). These choices are directly or indirectly driven by market prices of all outputs and inputs, levels of ecosystem service, other fixed inputs, and exogenous income. Thus we can describe WTP as a function of all these exogenous variables listed and measure it by estimating expenditure function or indirect utility functions (Freeman 1993). Alternatively, WTP can be measured as increases in producer surplus,  $\Delta\pi$ , if markets are complete (Pattanayak and Kramer

2001).<sup>5</sup> Ecosystem services are valued because they are expected to increase utility (and profits). Below we describe an approach proposed by Huang and Smith (1998) to estimate producer surplus changes with input demand functions that have special properties.

## 1.5 Weak Complementarity for Valuation

Much of the environmental valuation literature has focused on weak complements to environmental goods—goods that are nonessential inputs to household consumption (Freeman 1993). Analysts estimate how the demand for the weak complement shifts in response to changes in environmental quality and measure WTP for environmental quality as the change in consumer surplus. Huang and Smith (1998) develop production analogs of the weak complementarity logic to show that input demand can be used to measure the change in producer surplus induced by a change in environmental inputs into production. In this approach, shown in equation 20.1, WTP for ecosystem services ( $E_1 - E_0$ ) is estimated using Hotelling's lemma and the input demand curve,  $L(P_L | E, \bullet)$ .<sup>6</sup> Profits can be measured by integrating the input demand function from the market price,  $P_{L0}$ , to the choke price,  $P_{LC}(E)$ .

$$\begin{aligned}
 WTP &= \Delta \pi(P_Q, P_L | \Delta E, Z_Y) \\
 &= \int_{P_{L0}}^{P_{LC}(E_1)} L(P_L | E_1, \bullet) dP_L - \int_{P_{L0}}^{P_{LC}(E_0)} L(P_L | E_0, \bullet) dP_L \\
 &= \int_{P_{L0}}^{P_{LC}(E_1)} -\frac{\partial \pi(P_L | E_1, \bullet)}{\partial P_L} dP_L - \int_{P_{L0}}^{P_{LC}(E_0)} -\frac{\partial \pi(P_L | E_0, \bullet)}{\partial P_L} dP_L
 \end{aligned} \tag{20.1}$$

The choke price, at which labor demand ( $L$ ) is equal to zero, depends on the ecosystem condition. An improvement in the ecosystem that generates an ecosystem service will expand the demand for the weakly complementary production input, raise the choke price, and increase profits. WTP for the ecosystem service is, therefore, equal to the change in profits calculated from the two input demand curves. This logic is illustrated in figure 20.2. The basic intuition is that increased ecosystem service raises the value of the marginal product of farm labor because it is a complement. Consequently, the value of the ecosystem service or the amount the household will be willing to pay should equal the increased marginal value product of labor, which is equivalent to the profit increase.

There are two important theoretical conditions for application of the weak complementarity logic in ecosystem valuation. First, the production input in question must be nonessential, so that we can define a choke price.

Without this binding price, the compensation or surplus measure would be infinite (see Freeman 1993 for details). Second, at the choke price, the marginal productivity of ecosystem service must be zero, implying that the production input is a necessary complement to using the ecosystem service. If this were not the case, then we could not value the ecosystem service by analyzing only this production input, because the service would be productive irrespective of the demand for this input. In addition, the induced change in labor demand should not be large enough to induce labor price effects. Huang and Smith (1998) suggest that by focusing on the demand function for a weak complement (e.g., labor), researchers could substantially economize on the data demands for valuation by avoiding estimation of full profit functions (Pattanayak and Kramer 2001).<sup>7</sup>

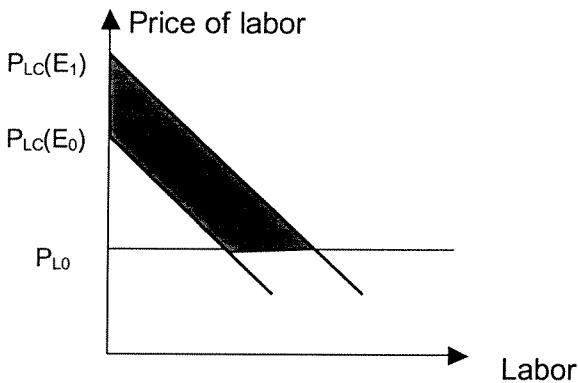


Figure 20.2. WTP for ecosystem service as change in area under demand curve of a weak complement: agricultural labor

## 2. THE CASE OF DROUGHT MITIGATION FROM RUTENG PARK ON FLORES, INDONESIA

Since the time of Dutch colonial rule, the forests of the Manggarai region on Flores Island have been protected to different degrees across watersheds. In 1993, the government of Indonesia established Ruteng Park on 32,000 ha to prevent further deforestation, initiate reforestation and land conservation, and enhance watershed protection. A recent evaluation of water resources in the region finds that the forests provide drought-mitigation service by protecting streams and rivers (Binnies 1994). Two forest hydrology studies in addition to the Binnies study suggest that in many Manggarai watersheds, forests are net producers of baseflow, the non-episodic residual streamflow



that is left over after rain has cycled out of the hydrological system (Swiss Intercooperation 1996, Priyanto 1996). We apply the three-stage framework to this case because the economic value of ecosystem services is unknown even though there is substantial biophysical evidence that Ruteng Park provides drought mitigation to the downstream farmers.

## **2.1 Applying the Freeman Framework to Ruteng Park**

In stage 1, we assume that the establishment of Ruteng Park produces a drought-mitigation service that can be measured as a change in baseflow. The forest hydrology literature posits that extensive tree cover helps maintain baseflow levels in areas with environmental characteristics similar to Ruteng, i.e., steep terrain, intense rainfall, and clayey and compacted soil (Bonell and Balek 1993). The studies by Binnies (1994), Swiss Intercooperation (1996), and Priyanto (1996) suggest that Ruteng forests are net producers of baseflow. The studies do not, however, report precise estimates of enhanced baseflow by watershed. In stage 2, the primary economic role of baseflow is as a fixed input in agricultural production; i.e., it provides soil moisture that enhances farm productivity. In stage 3, improved agricultural production changes the economic welfare of agricultural households downstream of Ruteng Park. This change in welfare is a measure of the value of drought mitigation. As shown above, the value of drought-mitigation services can be measured by computing the incremental producer surplus resulting from the incremental baseflow.

## **2.2 Ruteng Data**

The empirical model presented in the next subsection is based on secondary hydrological and forest statistics and household survey information on the economic activities of the Manggarai people. A water balance model was used to derive baseflow volumes for 37 subwatersheds in the buffer zone of the park, which correspond to current land use (Priyanto 1996). This cross-sectional variation in current baseflow is sufficient to econometrically establish the influence of baseflow on agricultural profits.<sup>8</sup> The household data are drawn from a socioeconomic survey of 500 households that was conducted in the Ruteng area in 1996. Because the hydrological effects of the park dissipate over geographical distance, the survey was restricted to the 47 villages in the buffer zone of Ruteng Park, contiguous to the protected area. The average Ruteng household exhibits a heavy reliance on agriculture, primarily growing coffee and rice and keeping chicken and pigs. Eighty-seven percent of the local people are employed in agriculture. There are a few nonagricultural employment opportunities,

including positions with the local government, nongovernmental organizations, kiosks, and logging crews. The statistics on both hiring-in and hiring-out labor, the fact that a large proportion of households report input and output prices, and the proximity of roads and other market infrastructure (e.g., stores and credit facilities) provide some evidence that markets are complete for agricultural products and labor. While the Ruteng region receives on average 2.5 meters of rainfall annually, only about 40% stays in the system as baseflow.

Given that we implement our empirical model by combining socioeconomic survey data with the ecological data related to the forest hydrology model, the precision of our ecological data is important. By merging the two data sets within a geographical information system (GIS), we can potentially improve the general precision of the data set and compute spatially explicit ecological indices. For example, if portions of two streams contribute baseflow to a particular village, we can use GIS to compute the fraction of the total baseflow from any one stream that goes to the particular village by first calculating the fraction of the total stream that passes over the specific village. The contributions of each stream can then be summed. Without GIS, we would calculate a crude weighted average of the baseflow in the two streams, based on eye-balled proportions. We investigate the implications of using data generated with and without GIS (analysis not reported in this chapter).

## **2.3 Valuation of Drought Mitigation**

Applying the Huang and Smith logic and focusing on demand for agricultural labor, we see that agricultural labor can be conceived as a weak complement to baseflow because it satisfies the two necessary conditions for weak complementarity. First, it is possible that labor demand is nonessential, so that at a choke price of  $P_{LC}$ , demand for labor is zero. Because nonagricultural sources of income make substantial contributions to household full income (note, not cash income), agricultural labor is a nonessential input to household full income as households switch to other activities when the price of labor is too high. Second, the marginal productivity of baseflow is zero at the choke price, implying that changes in baseflow have no welfare significance unless the effective wage is low enough to make labor demand positive. This follows from the fact that baseflow is useful to the farming households only as a farming input and it is impossible to farm without labor.<sup>9</sup> We estimate the three most common functional forms of labor demand: linear, log-linear, and semilog, described in equations 20.2 to 20.4:

$$\text{Linear: } L = \alpha + \beta P + \gamma Z \text{ and Welfare Est.} = \frac{\hat{L}_1^2 - \hat{L}_0^2}{-2\beta} \quad 20.2$$

$$\text{Log - linear: } L = e^{\alpha} P^{\beta} Z^{\gamma} \text{ and Welfare Est.} = \frac{P_0 \hat{L}_0 - P_1 \hat{L}_1}{\beta + 1} \quad 20.3$$

$$\text{Semilog: } L = e^{(\alpha + \beta P + \gamma Z)} \text{ and Welfare Est.} = \frac{\hat{L}_1 - \hat{L}_0}{-\beta} \quad 20.4$$

where  $\hat{L}_0$  and  $\hat{L}_1$  are the predicted baseline labor demand evaluated at mean wage with and without drought mitigation,  $\beta$  is the regression coefficient for wage, and  $Z$  is a vector of all other variables including output prices.<sup>10</sup>

Labor demand is hypothesized to be a function of the price of labor; the price of the primary outputs (coffee and rice); and fixed inputs, including baseflow, farm size, soil condition (erosivity), and an irrigation index. Table 20.1 summarizes the expected relationships.

The signs, sizes, and significance of the estimated coefficients are the criteria for evaluating the theoretical performance of our models. We expect labor demand to be negatively correlated with the price of labor. Because prices of rice and coffee reflect returns to labor in farming or the effective Note that the coefficient on erosivity should be negative because it is a negative fixed input. The key parameter in our model is the coefficient on the baseflow variable; its sign and the size will reflect the relative contribution or value of drought mitigation from the forests of Ruteng Park for the farming households. Finally, we include a set of household characteristics, family size, average age, and ratio of ill, adult, and male family members, to test the complete labor market assumption (Pattanayak and Kramer 2001).<sup>11</sup>

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Table 20.1. Descriptive statistics and expected signs

Variables	Units	Mean	Expected sign
Labor	Days	115.30	
Price of coffee	\$ per kilogram	1.78	(+)
Price of rice	\$ per kilogram	0.18	(+)
Price of labor	\$ per day	0.90	(-)
Farm size	Hectares	1.2	(+)
Water condition	Baseflow in meters / ha / year	0.4	(+)
Irrigation index	% of farm irrigated	0.1	(+)
Soil condition	Erosivity in tones / ha/ year	2.1	(-)
Family size	Number	4.3	~
Ratio of adults in family	Ratio	0.77	~
Ratio of ill in family	Ratio	0.77	~
Average age	Years	26.7	~
Ratio of males in family	Ratio	0.49	~

## 2.4 Three Estimated Models

The results of the three labor demand models, for each of the three functional forms (linear, log-linear, and semi-log), are reported in table 20.2.

Table 20.2. Models of labor demand

Variables	Linear	Log-linear	Semi-log
Constant	89.06 *	5.27	4.35
Price of coffee	20.86	0.09	0.07
Price of rice	256.01 ***	0.54 ***	1.80 **
Price of labor	-119.51 ***	-0.88 ***	-1.10 ***
Farm size	17.03 ***	0.15 ***	0.17 ***
Baseflow	69.54 ***	0.23 ***	0.67 ***
Irrigation	33.93 **	0.06 ***	0.52 ***
Erosion	-11.53 ***	-0.17 **	-0.12 ***
Family size	0.24	0.06	0.01
Adult ratio	43.91	0.08	0.32
Ill ratio	-4.80	-0.02	-0.02
Average age	0.36	0.15	0.00
Male ratio	-0.93	-0.02	-0.01
Adj. R <sup>2</sup>	0.16	0.15	0.15
F-statistic	8.96 ***	8.29 ***	8.22 ***
Sample size	494	494	494

\*\*\*, \*\*, \* = significant at 1%, 5%, and 10% level, respectively.

All models are statistically significant. The models explain about 14% to 20% of the variation in labor demand, which is not unusual in a cross-sectional data set. Although the log-linear model has the highest R<sup>2</sup>, all models have similar explanatory power. All variables have expected signs and significance in all models, except that price of rice is insignificant and

weakly related to labor-demand in the log-linear and semi-log models. All five household variables are individually and jointly insignificant in all models—validating the complete labor market assumption. Critically, baseflow has a positive and significant coefficient in all models.

2.5 Economic Value of Baseflow: Elasticity

The positive and significant coefficient of the baseflow variable supports the hypothesis that drought mitigation services enhance agricultural profits. To compare across models with different functional forms, we consider the elasticity of labor demand with respect to baseflow, which is a reflection of the marginal productivity. The precision with which we map the ecological data onto the economic model influences our estimate of the economic contribution of drought mitigation; mapping without GIS (not reported here) tends to overstate the economic contributions of baseflow. The estimated elasticities of 0.21 to 0.26 in Table 20.3 provide a credible approximation of the economic contribution of baseflow to agricultural profitability in Flores, Indonesia.

2.6 Policy Simulation: Valuing 10% and 25 % Increases in Baseflow

We do not have projections of the baseflow levels that will result from forest protection and regeneration in Ruteng Park. Therefore we evaluate two alternative forest hydrology scenarios in which forest protection induces baseflow increases of 10% and 25%. Using the welfare change formulae presented in equations 20.2 to 20.4 and the estimated parameters from table 20.2, we find that a 10% increase in watershed baseflow is estimated to increase profits by \$4 to \$25 or by 1% to 7% for the typical household. Note, a typical household is one with average household characteristics and profits equal to \$350 annually. A 25% increase in baseflow would increase profits by \$11 to \$65 or by 3% to 19%. The results are similar across functional forms. Collectively they suggest that ecosystem services in the form of increased baseflow can make substantial economic contributions to the farming households in the immediate downstream of the park.

Table 20.3. Elasticities and simulated values

Specification	Elasticity of labor w.r.t baseflow	Drought mitigation benefits of baseflow increase	
		10%	25%
Linear	0.26	\$5.39	\$13.95
Log-linear	0.23	\$25.18	\$65.28
Semilog	0.21	\$4.12	\$10.73

## **2.7 Policy Implications**

Hydrological stabilization, such that downstream drought conditions are mitigated, is one among several ecosystem functions of the forested watersheds within Ruteng Park. The estimated elasticity of 0.2 and the projected profitability increases of 5% to 10% reveal that watershed management that effectively mitigates drought could increase the annual agricultural profit of each household. Pattanayak and Kramer (2001) argue that increased forest cover will mitigate droughts by increasing baseflow only when the Ruteng watersheds have a particular mix of climatic and physiographic features, and therefore policy makers should adopt a selective approach targeting specific watersheds for forest conservation. We wish to emphasize that regardless of the mechanism that effectively mitigates drought, it is clear that increases in baseflow have positive economic value. While it is not our purpose to conduct a comprehensive cost/benefit analysis, the estimates of profit increases reported above can be compared with watershed regreening costs to judge the overall worthiness of investments in Ruteng Park. Finally, we reiterate that the value of drought mitigation constitutes just one element in the calculation of the net present value of the overall integrated conservation and development project for Ruteng Park. Thus, the net impact of reforestation may be positive when all benefits are considered.

## **3. INSIGHTS FOR FUTURE RESEARCH**

This case study shows that hydrological modeling can be combined with microeconomic techniques to value drought mitigation provided by forested watersheds in an agrarian region of Southeast Asia. The literature review and the mechanics of this case study offer insights for ecosystem valuation methods and future research that are described in detail in Pattanayak (forthcoming).

### **3.1 Insights for Ecosystem Valuation**

#### **3.1.1 Conceptual Framework**

The three-stage approach described in section 2 (and figure 20.1) organizes the valuation of ecosystem services in terms of changes in producer surplus. It presents a generalizable framework for measuring the economic value of ecosystem services as they contribute to production activities.

### 3.1.2 Indexing Ecosystem Services

As discussed by Freeman (1996), the key to ecosystem valuation lies in establishing the link between ecosystem function and some service flow valued by people. The Ruteng study offers two ideas regarding index construction, which is central to operationalizing Freeman's idea. First, the Ruteng study illustrates that cross-sectional variation in current levels of the ecosystem service, i.e., annual baseflow, enables analysts to generate useful policy information even without predictions of the changes in the ecosystem service that will result from policy changes and human behavior. Second, value estimates are significantly influenced by the degree of precision offered by GIS in measuring ecological variables such as baseflow.

### 3.1.3 Applying Weak Complementarity

The major advantage of weak complementarity, as opposed to estimating the full profit systems (Pattanayak and Kramer 2001), is data efficiency. In comparing ecosystem values for commensurable baseflow measures (non-GIS), we find that the welfare estimates are close—on the order of only a few dollars. The similarity of the two results suggests that the weak complementarity logic presents significant methodological efficiencies by using considerably fewer data. Estimates based on demand for a weak complement may be a lower bound of ecosystem loss when there is more than one such complement. As shown by Bockstael and Kling (1988), the weak complementarity logic can be applied to multiple market complements. In application the trick will be to find the most relevant or substantive complement. Labor productivity is the primary economic contribution of hydrological stabilization in our study area.<sup>13</sup>

## 3.2 Future Research

The method described in this chapter generates at best an approximate value of complex ecosystem services. For this and other reasons, Pattanayak (forthcoming) calls for the use of other methods to value ecosystem services, in addition to the profit/producer surplus-based approach, to judge the robustness of the empirical estimates. Although household and sample level values of ecosystem services are desirable policy information, their usefulness is limited to the socioeconomic and geographic context in which the values are derived. Given the costs of conducting new research for site-specific environmental resources, it is important to develop methods for transferring benefit estimates from one site to similar sites in a theoretically correct manner. Future research could focus on adapting the calibration

strategy described and illustrated by Smith et al. (2002) and on applying a meta-analytic approach for combining estimates from several existing valuation studies to develop a value function of ecosystem services.

#### 4. CONCLUSION

This chapter offers a conceptual and empirical framework for valuing ecosystem services and some suggestions for future research. Although forest protection is professed to generate several ecosystem benefits, recent surveys of valuation studies reveal that economic benefits of forest ecosystem services are not well understood and are rarely quantified (WRI 2000). We discuss issues surrounding valuation of forest ecosystem services and illustrate a method for valuing watershed services. We focus on estimating livelihood values to poor farming communities from protected tropical watersheds by estimating demand for a weak complement of ecological services—agricultural labor. We address these research issues with a case study from Indonesia in which forest protection policies in upstream watersheds in Flores stabilize hydrological flows in downstream farms.

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<sup>1</sup> Pattanayak (forthcoming) describes a subset of ecosystem services—watershed services—that include erosion control, enhanced soil quality, improved water yield, stabilization of streamflows, and sediment reduction.

<sup>2</sup> Such simplified addition is inappropriate because (1) forest ecosystem services are nondivisible and nonexclusive, (2) unit values do not reflect declining marginal willingness to pay (WTP), (3) interdependence among and changes in other ecosystem conditions are not considered, and (4) income and general equilibrium price effects are ignored.

<sup>3</sup> A resource accounting approach is characterized by project evaluation in which intertemporal cash flows are generated using parametric economic values drawn from secondary sources. In the econometric approach, simple production functions are estimated to relate agricultural production to soil erosion. A mathematical programming approach seeks an optimum, given an objective function that is subject to constraints with predetermined parameters.

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- <sup>4</sup> For example, under *household production theory*, households may combine goods such as water (from the streams in watersheds) and labor to provide a *service* such as drinking or cooking, which enhances *utility*. By comparison, conventional *production theory* would conceptualize streams (raw material) and labor as *inputs* in the production of water as an *output* that could then be sold or consumed. The relationship between the nonmarketed ecosystem service and market commodities falls under one of three general categories: complements, substitutes, or differentiated goods (Freeman 1993).
- <sup>5</sup> Pattanayak and Kramer (2001) show that the value of the ecosystem service can be measured by incremental profits that are equivalent to a change in household expenditures. The logic is that complete markets imply that market prices (used to calculate household profits), rather than a household-specific virtual price, reflect the relevant opportunity costs (used to calculate household expenditures). Therefore the increase in producer surplus or profits induced by the greater ecosystem service is equivalent to additional expenditures that the household would be willing to incur to realize the level of welfare associated with higher ecosystem services.
- <sup>6</sup> Hotelling's lemma states that the derivative of profits with respect to input price is equal to the input demand (Chambers 1988).
- <sup>7</sup> In a systems approach, we would estimate equations for profit, output supplies, and input demands as functions of prices and fixed inputs. Using weak complementarity, we could focus on one essential output supply *or* input demand and estimate it as a function of prices and fixed inputs; we would not need data on all quantities.
- <sup>8</sup> While cross-sectional data was sufficient for our purposes, undoubtedly time-series data would have been useful to validate such a model.
- <sup>9</sup> Benefits, measured as savings in water collection costs, were found to be insignificant in comparison to the agricultural productivity benefits (Pattanayak [forthcoming]).
- <sup>10</sup> If  $\beta < -1$  in the log-linear case, an adjusted formula, which is described in Adamowicz et al. (1989), must be applied to compute welfare changes.
- <sup>11</sup> If this set of five variables is statistically unrelated to labor demand, it would suggest that production decisions are made independent of consumption decisions, because the labor market is perfect and hired labor can be substituted for family labor.
- <sup>11</sup> If this set of five variables is statistically unrelated to labor demand, it would suggest that production decisions are made independent of consumption decisions, because the labor market is perfect and hired labor can be substituted for family labor.
- <sup>12</sup> In principle, we could estimate demand for each weak complement and calculate the relevant welfare values. Another advantage of this approach in the production setting, unlike the consumption setting where weak complementarity is a maintained hypothesis, is that the analyst can test for complementarity, because the relationship is a physical/technological association. Our results show that physical complementarity of labor and baseflow holds in Ruteng.